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Research Article

Evaluating the Nexus between Growth and Renewable Energy Consumption on CO_2 Emissions: Evidence from Pakistan

Hannana Gohar[1], Prof. Dr. Abdul Ghafoor Awan[2]

1. Research Scholar, Department of Economics, University of Southern Punjab, Multan, Pakistan.
hannana.gohar94@gmail.com

2. Dean, Faculty of Social Sciences, University of Southern Punjab, Multan, Pakistan.
drabdulghafoorawan@gmail.com Corresponding Author: Prof. Dr. Abdul Ghafoor Awan

Abstract

Countries make sustainable strategies to achieve sustainable development goals of the United Nations, but climate change undermines these efforts by eliminating all growth efforts. Pakistan is among those countries which has been facing climate change issues and its adverse effects on its economy in the form of billions of dollars economic loss every year. Hence, this issue needs to be explored to understand its causes and effects. The primary objective of this research is to investigate the nexus between climate change, renewable energy usage, trade openness, fossil fuels use, economic growth and $C0_2$ release in Pakistan using annual data spanning from 1990 to 2024 sourced from World Development Indicators, Pakistan Economic Survey, and State Bank of Pakistan. $C0_2$ emission is dependent variables and is proxied for environmental quality while explanatory variables include climate change, renewable energy use, trade openness, fossil fuels usage and economic expansion. The study employed Correlation Matrix and ARDL approach to estimate the relationship between climate change, renewable energy usage, trade openness, fossil fuel usage, economic growth and CO_2 emissions. The findings reveal that climate change, economic expansion, fossil fuel usage, and trade openness exert significant positive impact on CO_2 emissions, whereas renewable energy use has negative effect on it, showing its positive role in environmental improvement.

Key words: Renewable Energy use; CO2 emissions; Trade openness, Economic growth; Fossil Fuel use.
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1.Introduction

1.1 Background of Study

The rising level of CO2 releases in the atmosphere have fastened ecological decline and climate change and are the top issues in today's economic and policy debate. Emissions are considered the key driver of global warming and ecological decline. Recent reports show that global CO_2 emissions have reached record levels due to fossil fuel use and increased economic activity (International Energy Agency, 2025). Fast population growth, industrialization, and surging power demand have further exerted pressure on the environment in developing economies like Pakistan.

Climate change has been quantified through temperature fluctuations, as the deviation from long-term climatic average level helps to understand warming trends. According to the Pakistan Meteorological Department (2021), since 1960, mean annual temperatures have increased at a rate of about 0.099°C per decade, and recent variations going beyond 0.4°C relative to the 1961–1990 baseline. The empirical study of Sarfaraz and Nazir (2023) support these trends by identifying significant increased in mean, maximum, and minimum temperatures in all provinces of Pakistan in the last 63 years. Similarly, Nawaz, & Khurshid,2022; Hafiza Nida et al. (2025) also noted a significant rise in extreme temperature indices, such as rising in the frequency of hot days and warm nights from 1981 to 2020, proving abnormal climate variations. Rab Nawaz and Khurshid 2022; Nida, et al., (2025) reported that the temperature anomalies in some major urban areas of Pakistan have turned from negative to positive, indicating structural change in energy system. Collectively, these studies establish temperature anomaly as a widely accepted proxy for climate change in Pakistan, effectively capturing long-term warming trends rising climatic variability.

Energy consumption patterns become a key determinant of environmental footprints. While non-renewable are the leading factor of CO_2 emissions. Empirical evidence from Pakistan shows that renewable energy adoption significantly reduces CO_2 releases over time, while fossil fuels are responsible for environmental decline Qudrat-Ullah, 2022; Ali, 2024; Imtiaz, (2025). Similarly, cross-country studies show that fossil fuel-based energy systems are associated with high carbon emissions whereas renewable energy is helpful in reducing ecological footprints (Mamkhezri, & Khezri, 2024).

Trade Openness is also a major determinant of environmental quality. This may boost industrial output and energy use, leading to higher emissions. At the same time it can promote the use of cleaner technologies and environmentally friendly practices. Empirically, trade openness has a significant effect on CO2 emissions, but the relationship is based on the trade structure and regulatory framework (Khawaja, 2025). This finding supports the "pollution haven" hypothesis theory, which states that underdeveloped countries allow dirty industries to operate (Bhayana & Nag, 2024).

Another dimension to the interrelationship between development and environmental sustainability is economic growth. It is generally believed that growth is the most important factor in improving the standard of living . However, growth is also often associated with higher energy consumption and environmental degradation in the early stages of development. As per *Environmental Kuznets Curve (EKC) hypothesis*, ecological degradation first increases with economic expansion, then decreases with increasing per capita income and adoption of cleaner technologies Awan, 2014; Khan et al., 2024). However, recent global studies show that balanced growth-emission is still a serious issue in developing countries (Energy and Climate Intelligence Unit, 2025).

Recent empirical evidence has established that renewable energy drastically decrease carbon emissions in Pakistan (Awan, 2015; Bashir & Awan, 2025; Gull et al., 2025; Imtiaz, 2025; Mamun & Ehsanullah, 2025). However, the pace of clean energy adoption is slow due to high upfront costs, and existence of large-scale traditional energy structure and huge replacement cause. Hence, the primary objective of this study is to examine the determinants of CO_2 emissions in Pakistan by analyzing the combined effects of climate change, renewable energy usage, fossil fuel consumption, trade openness, and economic expansion over the past 35 years. The findings of previous studies remain inconclusive and poor, especially with respect to the roles of renewable energy and trade openness in mitigating ecological decline, thereby highlighting significant research gaps and needs for further deeper investigation. To address this gap, the present study undertakes an integrated analysis of these key constructs within a single econometric framework. The key objectives of the study are as follows:

- To see the statistical link between climate change and CO_2 releases in Pakistan.
- To investigate the impact of renewable energy usage on CO_2 emissions in Pakistan.
- To examine the effect of fossil fuel usage on CO_2 emissions in Pakistan.
- To assess the influence of trade openness on CO_2 emissions in Pakistan.
- To determine the statistical association between economic expansion and CO_2 releases.

In line with these objectives, the study intends to explore the following research questions:

RQ1: What is the statistical relationship between climate change and CO_2 emissions?

RQ2: How does renewable energy usage influence CO_2 releases and ecological uplift in Pakistan?

RQ3: Do fossil fuels usage significantly influence CO_2 emissions and contribute ecological. decline?

RQ4: How does trade openness enhance CO_2 emissions through the channel of economic.

expansion in Pakistan?

RQ5: Has economic expansion adverse impact on CO_2 releases and spoil clean environment?

The remaining manuscript is divided into following sections. Section **2** provides theoretical and empirical analysis, besides identifying research gaps and developing hypotheses; section **3** discusses research design, econometric model, and analytical technique; section **4** explains estimated empirical results; section **5** examines findings, practical implications, theoretical contribution, limitations, and new areas of research.

2. Theoretical and empirical review

2.1 Theoretical Foundations

Several established theoretical viewpoints in economics and environmental sciences can be applied to analyze rising CO_2 emissions and the declining state of clean environment. The core framework is the Environmental Kuznets Curve (EKC), which depicts the non-linearity, inverted-U shape between economic growth and environmental deterioration. In the early phases of development, with the expansion of industries and urbanization, the pressure on the environment is likely to increase. However, once a certain income threshold is reached, the environment begins to improve because cleaner technologies are adopted and stricter anti-pollution laws are enforced (Khan et al., 2024). Although numerous empirical studies support the EKC proposition, its applicability to developing economies, including Pakistan, remains a topic of debate among scholars (Shang et al., 2024). The next important theoretical lens is the Pollution Haven Hypothesis (PHH), which states that multinational corporations often dirty industries to countries where regulatory standards are comparatively weak. This suggests that trade openness increase can be a determinant factor for the increase in CO2 emissions in developing countries (Bhayana & Nag, 2024: Van de Ven. et al. (2026). On the other hand, the Pollution Halo Hypothesis offers a rosy

view, suggesting that trade openness can improve the environmental quality by diffusing advanced technologies.

The theory of anthropogenic global warming (AGW) explains the causes of global warming and intensification of climatic variations. This theory draws attention to the role of human activities in disturbing the natural equilibrium of the climate system of the earth through the increased level of greenhouse gases. This theory identified man-made CO_2 emissions as a major cause of extreme weather and environmental instability.

In addition, *Energy-Led Growth Theory* offers insight into the link between energy use and economic expansion. It argues that energy use is a fundamental driver of economic growth, implying that limiting energy use may hinder development. This theory does not differentiate between renewable and non-renewable energy sources, despite their markedly different environmental impacts. However, rising investment in renewable energy and green technologies offers a practical pathway to reduce emissions while maintaining economic expansion, thereby supporting long-term sustainability goals (Gull et al., 2025).

2.2 Climate Change and CO_2 Emissions

Climate change and CO_2 release are interrelated because greenhouse gases, the primary driver of climate change, are close link with it (Awa, 2016; Umar, & Raza, (2023). Most studies take CO_2 releases as an antecedent of climate change; however, latest scholarly literature have also focused on feedback mechanisms, whereby climate-related variables influence emission patterns through changes in energy demand and policy responses. The International Energy Agency (2025) indicates that rising global temperatures and climate-related risks have led many countries to formulate emission-reducing policies. Climate vulnerability in Pakistan has increased the pace toward sustainable energy systems. However, very few empirical works have attempted to study the direct association of climate change indicators with CO_2 emissions, especially in developing economies like Pakistan (Shahzad, et al., (2017; Abebaw, (2025). Hence, we can hypothesize that**:**

H1: Climate change has a statistically significant positive impact on CO_2 releasees.

2.3 Nexus between renewable and non-renewables and CO_2 Emissions

The academic literature has identified a close link between energy use and CO_2 releases. For instance, Khan, Ahmad, & Ullah, (2024) concludes that consuming fossil fuels has a positive and statistically significant impact on CO_2 releases in Pakistan over time. However, the study identified that renewable energy use is widely considered as one of the best channels to reduce ecological decline. Mohiuddin, Asumadu-Sarkodie, & Obaidullah, 2016; Ali, (2024) argues that the use of renewable energy reduces CO_2 releases in Pakistan, which indicates its potential to ensure environmental sustainability. Similarly, (Gull et al., 2025) emphasized that renewable energy adoption could reduce carbon intensity. However, some studies have argued that the effect of green energy on CO_2 releases depends on the scale of its adoption and the total energy mix. In the countries where renewable energy accounts for a small share of total energy use, the impact on emissions will be very low, thus, indicating the necessity of a full transition to cleaner energy systems. Therefore, we can hypothesize that:

H2: Fossil fuel use has significant positive influences on CO_2 releases.

H3: Renewable energy use has significantly negative impact on CO_2 releases.

2.4 Trade openness and Ecological deterioration

Trade openness affects environmental footprints in two ways. While openness to trade may increase emissions through enhanced industrialization and energy use, it may also reduce them through access to cleaner technologies. Khawaja (2025) argues that trade openness significantly affects CO_2 releases in Pakistan; however, this relationship depends on the trade composition. This is in line with the *Pollution Haven Theory*, which concludes that developing countries are facing higher levels of emission due to the relocation of pollution-

intensive industries (Bhayana & Nag, 2024). At the same time, empirical evidence also supports the *Pollution Halo Theory*, suggesting that trade can improve environmental quality under some conditions. This duality indicates that the pollution effects of trade relieve the legal structure and technological use. Hence, we can hypothesize that:

H4: Trade openness has significant positive influence on CO_2 releases.

2.5 Nexus between Economic Growth and Ecological decline

Many studies have investigated the link between economic expansion and CO_2 releases. While some studies support the EKC hypothesis, others found a monotonic relationship between growth and emissions. Işık, et al., (2024; Khan et al. 2024; Alam, et al., (2024) supported the EKC framework for Pakistan, arguing that environmental decline increases with economic expansion at the earlier stage and declines beyond a certain level of income. On the other hand, recent studies claim that the EKC hypothesis does not hold for all economies specifically for developing economies due to continuation of traditional energy production systems. The Energy and Climate Intelligence Unit (2025) disclosed that some countries have managed to decouple economic uplift from carbon emissions, but this is not a normal practice for all. The mixed results imply the complexity of the growth–environment nexus, suggesting that the effect of economic uplift on CO_2 emissions depends on a country's energy structure, technological advancement, and environmental policy. Hence, we can hypothesize that:

H5: Economic expansion has significant positive effects on CO_2 expansion.

2.6 Synthesizing literature and Research Gap

While the existing body of literature on the drivers of CO2 releases offers valuable insights, several critical gaps remain. First, key determinants like energy use, economic expansion and trade openness are mostly studied in isolation, opting for an integrated framework limits the understanding of its dynamics over time. Second, while the importance of

renewable energy in curbing emissions is acknowledged, no proper consideration has been given to its long-term implications, especially for developing countries like Pakistan. Third, the environmental consequences of trade openness continue to be ambiguous as empirical evidence presents conflicting results for both Pollution Haven and Pollution Halo hypotheses. Moreover, few researchers have considered climate change explicitly as an influential determinant in CO_2 emission models. Moreover, a major methodological limitation persists in literature. Many studies use single-equation approaches or short time spans that may not be able to capture long-run dynamics. The use of more robust econometric techniques like ARDL model to estimate both short-term and long-term relations has not been investigated in case of Pakistan. To overcome these limitations, this study develops a comprehensive framework considering simultaneously the climate change, renewable energy use, fossil fuel use, trade openness and economic expansion. This study aims to shed more light on environmental dynamics and policy-related implications for sustainable development through the application of time-series data and advanced econometric methods.

3. Research Methodology

The present study mainly aims at examining the impact of climate change, trade openness, fossil fuel consumption, economic growth and renewable energy consumption on carbon dioxide emissions in Pakistan.

3.1 Data and sources

The analysis is based on time series data taken from authentic sources such as World Development Indicators (WDI), International Energy Agency (IEA), Pakistan Economic Survey, Pakistan Bureau of Statistics and State Bank of Pakistan. The dataset covers the period from 1990 to 2024, allowing for a comprehensive time series analysis of the variables' short-run adjustments and long-run equilibrium. Using secondary data

helps to improve consistency, reliability and comparability over time.

3.2 Selected Variables

The selection of variables is grounded in well-established economic and environmental theories. The dependent variable is CO2 release per capita (in metric tons) which is used as an indicator of ecological decline. The explanatory variables are economic growth (GDP), renewable energy use (share of total energy use), trade openness, fossil fuel use and a proxy for climate change. Temperature anomalies provide a meaningful picture of global warming as they are long-term deviations in temperature patterns and represent climate change. This proxy is often used in environmental economics to measure the effect of climate change on environmental quality. These variables together capture the economic, structural and energy related dimensions affecting emissions in Pakistan. The study's variables, their definitions, measurement, and sources are summarized in Table 1.

Table1: Variables, Definitions, Measurements, and Sources

Variable	**Descriptions**	**Measurement**	**Sources**
Carbon Dioxide Emissions (CO_2)	The level of ecological decline caused by the release of greenhouse gases, primarily from fossil fuel combustion.	Metric tons per capita	Dilanchiev, Umair, M & Haroon. (2024); Tagomori, Diuana, Baptista, et al. (2026)
Climate Change (Temperature Anomaly)	Reflects variations in temperature causing global warming.	Temperature anomaly (°C deviation from 1961–1990 baseline)	Pakistan Meteorological Department (PMD); Van de Ven. et al. (2026)

Variable	Descriptions	Measurement	Sources
Renewable Energy use (REC)	Share of energy produced from renewable sources.	Percentage of total final energy usage (%)	Akbar, et al., (2024); Ali, (2024).
Fossil Fuel Consumption (FFC)	Use of non-renewables in energy production and consumption.	Percentage of total energy use (%) or energy consumption (kg of oil equivalent per capita)	Pakistan Economic Survey, 2023; Akbar, et al., (2024).
Trade Openness (TO)	Level of a country's integration with the global economy through trade.	Ratio of total trade (exports + imports) to GDP (%)	Pakistan Economic Survey, 2024; Khawaja, (2025).
Economic Expansion (GDP)	Total production of goods and services in a country in a specific year.	Annual GDP growth rate (%)	World Development Indicators (WDI); Pakistan Economic Survey, 2024.

Source: Author compilation.

3.3 Model specification

The empirical model reflecting the functional linkage between CO_2 emissions and its determinants is shown in the following equation:

$$CO_{2t} = \beta_0 + \beta_1 GDP_t + \beta_2 REC_t + \beta_3 TO_t + \beta_4 CLC_t + \beta_5 FFC_t + \varepsilon_t \quad (1)$$

To improve interpretability and reduce heteroscedasticity, the model is transformed into logarithmic form:

$$LnCO_{2t} = \beta_0 + \beta_1 LnGDP_t + \beta_2 LnREC_t + \beta_3 LnTO_t + \beta_4 LnCLC_t + \beta_5 LnFFC_t + \varepsilon \quad (2)$$

where ε_t represents the error term, and the coefficients (β_1–β_5) capture the elasticity of CO_2 emissions in relation to each explanatory variable.

3.4 Estimation Techniques

The ARDL modeling approach was used because it is suitable in cases of small sample sizes and integration of variables at order, I (0), and I (1). To estimate long-term relationships between variables the Bound testing approach was used. Further, the Error Correction Model was applied to identify short-run deviations and the speed of adjustment to long-run equilibrium. Before estimating, the ADF and PP test were performed on variables to identify their stationarity properties. Correlation method was also used to check the strength of correlation between pair of variables. The methodological approach adopted herein reflects a multi-layered approach to the interactions of economic expansion, energy use, and environmental sustainability in Pakistan. Based on hypotheses of the study we created a conceptual model, which shows link between explanatory and explained variables. The model is shown in Figure 1.

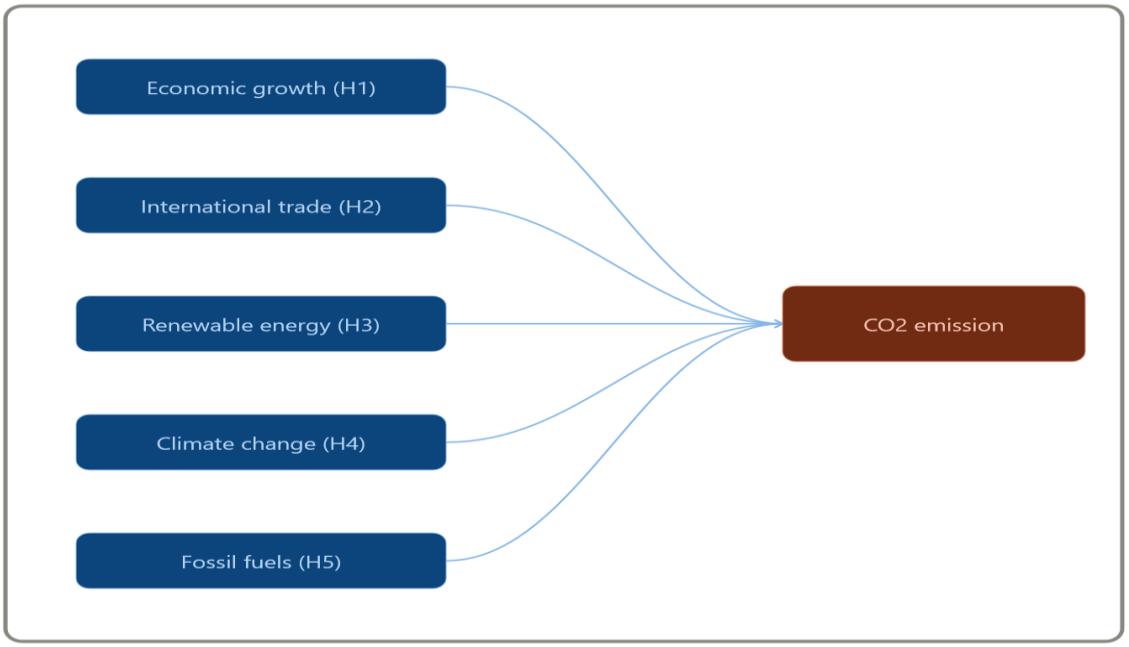

Fig 1: Hypothesized Model

4. Results

We will discuss the numerical results derived from various econometric techniques through E-view software. We will also check the robustness of the model and normal distribution of error terms through different diagnostic tests. Now we discuss the estimated results one by one.

4.1 Descriptive Analysis

Descriptive analysis is used to summarize, organize, and present data in clear way to understand its patterns and characteristics. This analysis helps scholars simplify big and complicated datasets by offering measures such as averages, percentages, and variability, which make it easier to explain overall distribution of the data. Thia analysis also provides

a clear picture of the data, facilitating policymakers and researchers to make informed decisions and interpret results accurately. Table 2 demonstrates the outcomes of descriptive analysis.

Table 2: Descriptive analysis results

LNCO2	GDP	REC	CLC	FFC	TO
0.744333	4.598881	48.03004	20.57956	60.07199	29.98975
0.729658	4.262497	47.40000	20.69286	59.83000	30.89027
0.988517	8.202456	54.31349	21.41462	66.28000	38.33013
0.568343	0.038893	41.60000	19.44474	55.16519	21.45996
0.118769	1.953136	3.960352	0.453555	3.182167	4.098879
0.316965	-0.064982	-0.038816	-0.707209	0.333944	-0.174715
2.016208	2.816170	1.764247	2.790976	2.143042	2.350493
1.997498	0.073915	2.235789	2.981224	1.721493	0.793277
0.368340	0.963717	0.326967	0.225235	0.422846	0.672577
26.05164	160.9608	1681.051	720.2845	2102.520	1049.641
0.479603	129.7012	533.2693	6.994208	344.2904	571.2276
35	35	35	35	35	35

Source: Author owns calculation using E-view Software.

Table 2 shows 35 observations for LNCO2, GDP, REC, CLC, FF, and TO in the dataset. All variables are normally distributed, as indicated by the proximity of the mean and median values. While LNCO2 exhibits comparatively little variation over time, REC exhibits significant variation (high standard deviation). The values of skewness and Kurtosis also show normal distribution of the variables. Thus, the data are appropriate for conducting further econometric analysis.

4.2 Unit Root Test

Tow popular tests such as the Augmented Dickey–Fuller (ADF), and Phillips–Perron (PP) tests were performed to identify stationarity in time series. Stationarity is necessary in time-series data analysis because non-stationary data can produce spurious regression findings. The ADF test depicts higher-order of integration by including lagged differences of the variable, while the PP test indicates serial correlation and heteroskedasticity using non-parametric corrections. Collectively, these tests help the scholars specify correct econometric models such as ARDL or cointegration analysis to compute valid results. The results of ADF and PP tests are presented in Table 3.

Table 3: Unit Root Tests outcomes

Results of ADF and PP Tests				
variables	ADF		PP	
	Level	1st Difference	Level	1st Difference
CO2	0.5277	0.0000	0.5770	0.0000
GDP	0.0025	0.0000	0.0023	0.0000
REC	0.7369	0.0001	0.8260	0.0000
FFC	0.8178	0.0000	0.8380	0.0000
TO	0.2053	0.0000	0.1577	0.0000
CLC	0.0302	0.0000	0.0319	0.0000

Source: Author owns calculations using E-view software.

The results show that the probability values of variables (CO2, REC, FF, IT, and CLC) are higher than 0.05, which confirms that variables are non-stationary at the level. However, because their p-values are 0.0000 or extremely low (less than 0.05), they become stationary

at first difference. In both the ADF and PP tests, GDP is stationary at the level (p-value < 0.05). Hence, the data is valid for using the ARDL model for further analysis.

4.3 Correlation Analysis

Correlation matrix is an important statistical tool to measure the strength and direction of associations among multiple variables in a dataset. It helps Scholars identify whether variables are positively or negatively correlated and how strongly they move together in the same or opposite directions. This tool is useful for detecting potential multicollinearity issues before applying regression models, as highly correlated explanatory variables can distort findings. The outcomes of Correlation matrix are presented in Table 4.

Table 4: Correlation analysis results

	LNCO2	REC	GDP	FFC	CLC	TO
LNCO2	1	-0.961972	0.238927	0.944387	0.676188	-0.324456
REC	-0.961972	1	-0.202122	-0.965650	-0.694084	0.327913
GDP	0.238927	-0.202122	1	0.091190	0.212521	-0.277038
FFC	0.944387	-0.965650	0.091190	1	0.687881	-0.344901
CLC	0.676188	-0.694084	0.212521	0.687881	1	-0.544859
TO	-0.324456	0.327913	-0.277038	-0.344901	-0.544859	1

Source: Author owns calculations using E-view software.

The key findings of Correlation analysis demonstrate that the dependent variable $LNCO_2$ shows a strong negative correlation with REC (-0.9619), proving that higher renewable energy use is associated with a substantial decline in CO_2 releases. Conversely, $LNCO_2$ has a very strong positive correlation with fossil fuel use (FFC) (0.9443), suggesting that FFC

significantly increases CO_2 releases. It also shows a moderate positive correlation with CLC (0.6761), confirming that climate-related factors significantly contribute to higher emissions, while trade openness (TO) has a weak negative correlation (-0.3244) with emissions.

Renewable energy use (REC) is negatively correlated with FFC (-0.9656), suggesting that countries relying more on renewable energy systems tend to use less fossil fuel. REC also has a moderate negative relationship with CLC (-0.6940) and a weak positive correlation with trade openness (0.3279). Similarly, Economic expansion (GDP) shows weak links with most variables, suggesting a limited direct linear association among them. It is slightly positively correlated to $LNCO_2$ (0.2389) and CLC (0.2125) but negatively correlated to REC (-0.2021) and TO (-0.2770). Fossil fuel use (FFC) exhibits a very strong positive correlation with CLC (0.6878) and a moderate negative link with trade openness (-0.3449), reinforcing its key role in ecological decline. Climate-related factors (CLC) are strongly associated with main variables, especially FFC and $LNCO_2$, while showing a moderate negative link with trade openness (-0.5448). In short, the correlation analysis demonstrates that fossil fuel use is the key driver of CO_2 releases, whereas renewable energy use plays a significant role in pollution reduction. Trade openness and GDP depict weaker and mixed correlations, suggesting their indirect or complex impact on ecological footprints. These results are further highlighted in Figure 2.

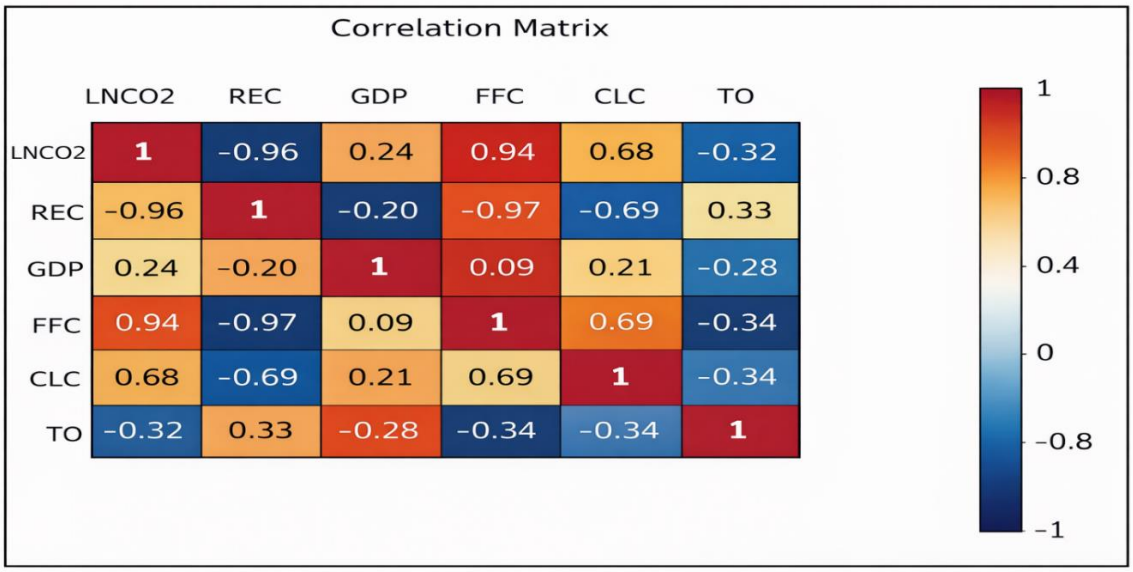

Fig 2: Heat map of Correlation analysis

The heatmap is a graphical representation of the correlation matrix, where the color shows the strength and direction of relationships between variables. The red hues in the map represent positive correlations (values near +1), while the blue hues indicate negative relationships (values near −1). The strongest correlation can be observed: LNCO2–FFC (deep red) showing a strong positive correlation, REC–FFC and LNCO2–REC (deep blue) indicating strong negative correlations. However, moderate correlations are seen in lighter red/blue colors, e.g. between CLC and FFC or $LNCO_2$. GDP and TO display weak correlations, seen in lighter colors near neutral.

4.4 ARDL long-run estimates

For empirical research, the scholars use Autoregressive Distributed Lag (ARDL) model because it is suitable for estimating short and long run co-integration among variables in the single model having small sample size. This model has the big advantage of being more flexible than the traditional cointegration techniques. The model also provides clear estimates of long run coefficients and short run adjustment through the Error Correction

mechanism and thus, is very useful in empirical studies analyzing energy consumption, economic growth and ecological impacts. The findings of ARDL model are presented in Table 5.

Table 5: ARDL Model Long-Run Estimates

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**	**Hypothesis Testing**
REC	-0.004529	0.009769	-0.463636	0.0020	H_0 rejected ($p < 0.05$) — significant negative long-run effect
GDP	0.049329	0.011269	4.377316	0.0047	H_0 rejected ($p < 0.05$) — significant positive long-run effect
FFC	0.024183	0.009660	2.503468	0.0463	H_0 rejected ($p < 0.05$) — significant positive long-run effect
CLC	0.061562	0.064863	0.949106	0.0030	H_0 rejected ($p < 0.05$) — significant positive long-run effect
TO	0.010804	0.004894	2.207636	0.0000	H_0 rejected ($p < 0.01$) — highly significant positive long-run effect

Variable	Coefficient	Std. Error	t-Statistic	Prob.	Hypothesis Testing
C	-2.310031	2.270583	-1.017374	0.3482	H_0 not rejected ($p > 0.10$) — constant term statistically insignificant

*Dependent variable**:** CO_2 emissions

Table 5 shows the long-run estimates of the ARDL model that show the long-lasting relationships between the explanatory variables (renewable energy consumption, GDP, fossil fuel consumption, climate change and trade openness) and CO2 emissions after the short-run dynamics have been exhausted. The coefficient of Renewable energy consumption -0.004529 is negative and statistically significant (p = 0.0020), which indicates that REC reduces CO2 emissions in the long run. Specifically, a unit increase in the consumption of renewable energy is associated with a decrease of approximately 0.0045 units in CO2 emissions, ceteris paribus. The size is small. But the finding is consistent with theory that moving to cleaner energy sources helps mitigate environmental degradation, which supports energy-transition and decarbonization policies. The coefficient of Economic Growth is positive and statistically significant with p = 0.0047 and value of 0.049329. In the long run, economic growth leads to increased CO2 emissions. This result is in accordance with the traditional growth-emissions nexus and the first (upward sloping) phase of the EKC hypothesis linking economic growth with higher energy consumption and industrial activity, and consequently, higher emissions, before a decoupling process at higher income levels. The positive coefficient (0.024183) for Fossil fuel consumption is significant at 5% level (p = 0.0463) confirming fossil fuel consumption contributes to the rise of CO_2 emissions in the long run**.**

This is an intuitive result as fossil fuels are a main source of carbon emissions, but the significance is only marginal (close to the 0.05 threshold), suggesting the effect is real but less robust than some of the other estimated relationships. Climate change/climate related indicator (CLC): The coefficient for Climate change/climate change-related indicators is positive and significant (p = 0.0030) and is 0.061562 which is the largest marginal effect of all explanatory variables. This indicates a positive and significant association of climate-related pressures (or, depending on the operationalization of CLC, climate-vulnerability/temperature-related factors) with CO_2 emissions in the long term, suggesting a potential feedback loop whereby deteriorating climate conditions and persistent high emissions are mutually reinforcing. The coefficient for Trade openness (0.010804) is positive and is highly significant with a p-value of 0.0000. This implies that an increase in trade openness increases long-run CO2 emissions. This result is consistent with the "pollution haven" view that the rise in trade intensity would increase the production, transportation and scale of the industrial sector, thereby increasing energy consumption and associated emissions. Constant (C): The intercept value (-2.310031) is statistically insignificant (p = 0.3482), which means that the baseline/autonomous level of CO_2 emissions, net of the explanatory variables, is not significantly different from zero. This is a common outcome in ARDL long run models and does not affect the validity of the other coefficient estimates. The overall explanatory power and statistical adequacy of the long-run ARDL model are strong and the value of R^2=0.941 indicates that the model explains approximately 94.1% of the variation in CO_2 emissions, indicating an excellent overall fit. The value of Adjusted R2 shows that after adjusting for the number of regressors, the model still explains about 92.8% of the variation, confirming that the high explanatory power is

not simply an artifact of including many variables — the model retains strong explanatory strength even after this correction. The low Standard of Regression = 0.0138 indicates that the fitted values are close to the actual observed values, reflecting a precise model fit. The value of F-statistic = 73.84, Prob (F-statistic) = 0.0000 is highly significant, confirming that the explanatory variables jointly and significantly explain variations in CO_2 emissions — the overall model is statistically valid and not the result of chance. Durbin–Watson Statistic = 2.06 is close to 2, which indicates the absence of first-order autocorrelation in the residuals, meaning the model's error terms are serially independent and the estimates are reliable/unbiased in this respect. The summary of the model is presented in Table 6.

Table 6: Model Summary (ARDL Long-Run Model)

Statistic	**Value**
R^2	0.941
Adjusted R^2	0.928
Standard Error of Regression	0.0138
F-statistic	73.84
Prob (F-statistic)	0.0000
Durbin–Watson Statistic	2.06

Source: Author owns calculations using E-View software

The conclusion from Tables 5 and 6 indicates that the ARDL model is both statistically robust and well-specified. The high R^2 and significant F-statistic confirm strong overall explanatory power and joint significance of the regressors, while the Durbin–Watson statistic confirms the residuals are free from autocorrelation. The long-run coefficients confirm a valid and interpretable cointegrating relationship: renewable energy consumption mitigates CO_2 emissions, while GDP growth, fossil fuel consumption,

climate-related pressure, and trade openness all contribute to higher long-run emissions. The ARDL model outcomes are further highlighted in Figure 3.

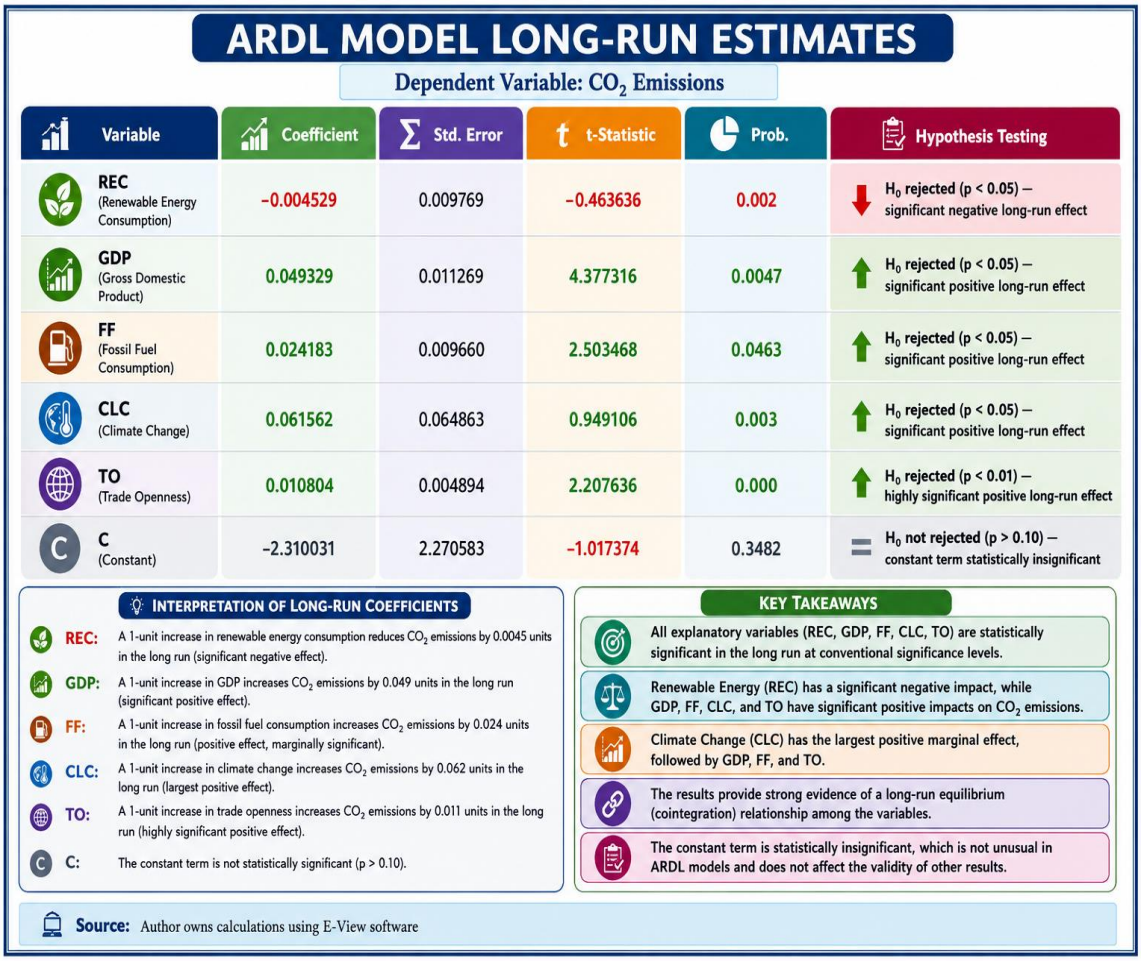

Fig 3: ARDL long-term estimates.

4.5 F Bound Test

The Bounds test is used to identify a long run cointegration among variables. This tool can be applied when variables are a mix of I (0) and I (1), unlike other cointegration tests that

require the same order of integration. This test compares the calculated F-statistics with critical upper and lower bounds: if the value is above the upper bound, a long-run relationship exists; if it is below the lower bound, no long-term correlation exists. In this way, the Bounds test provides a reliable tool to confirm whether variables move together in the long run before estimating long-run coefficients. Table 7 shows the results of Bound test.

Table 7: Bound Test Results

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I (0)	I (1)
			Asymptotic: n=1000	
F-statistic	3.804995	10%	2.07	3
k	5	5%	2.40	3.37
		2.5%	2.8	3.72
		1%	3.05	4.16

Source: Author owns calculations using SPSS Software.

The computed F-statistics (3.804995) in Table 6 are higher than the upper bound critical values. We reject the null hypothesis which assumes that there is no long-term linkage between variables. This demonstrates that variables in the model have a long-term cointegration.

4.6 Error Correction Model (ECM)

This model captures adjustment process by error correction term, which reveals the speed at which deviations from the long-run equilibrium are corrected. In this way, the model is useful because it combines short-run deviations with long-run equilibrium behavior in a

single framework, making it a more powerful tool for analyzing dynamic relationships among variables. Table 8 presents the ECM's findings.

Table 8: Error Correction Model (ECM) Results (Short-run Dynamics)

Variables	Coefficient	Std. Error	t-Statistic	Probability
D(REC)	-0.00291	0.00142	-2.05	0.0521
D(GDP)	0.03648	0.01185	3.08	0.0064
D(FFC)	0.01867	0.00781	2.39	0.0285
D(CLC)	0.03129	0.02371	1.32	0.2016
D(TO)	0.00796	0.00372	2.14	0.0469
C	-0.25483	0.11742	-2.17	0.0428
ECT(-1)	**-0.935184**	**0.128132**	**-7.298626**	**0.0003***

Dependent Variable**:** D($LNCO_2$)

The ECM estimates indicate the short-run dynamics among variables such as renewable energy consumption (REC), gross domestic product (GDP), fossil fuel consumption (FFC), climate change (CLC), trade openness (TO), and carbon dioxide (CO_2) emissions. In the short run, GDP and fossil fuel use have positive and statistically significant effects on CO_2 emissions, confirming that economic growth and extraordinary dependence on non-renewables increase environmental deterioration. Renewable energy use has a negative coefficient, indicating that rising renewable energy use contributes to reducing CO_2 emissions in the short run, although its impact is only marginally significant.

The effect of climate change (CLC) is positive but insignificant statistically, which implies that the short-run effect of CLC on emissions is weak. The results show that trade openness

has a positive and statistically significant effect on CO2 emissions, meaning that higher trade openness could put a little more pressure on the environment.

The Error Correction Term (ECT(-1)) is negative (-0.935184) and significant at 0.0003 which indicates the presence of a stable long-run relationship among the variables. The coefficient suggests that about 93.5% of any short-run disequilibrium is corrected in one period. This implies that the adjustment to the long-run equilibrium after short-term disturbances is very rapid. The result confirms the ARDL cointegration results are valid

4.7 Robustness checking through diagnostic tests.

We used various diagnostic tests to check multicollinearity and Heteroscedastic problems as well in the model. The combined results of these tests are presented in Table 9.

Table 9: Combined Diagnostic and Robustness Test Results

Test Type	Statistic	Value	df	Probability (p-value)	Decision
1.Ramsey RESET Test	t-statistic	0.285202	26	0.7777	Insignificant
	F-statistic	0.081340	(1, 26)	0.7777	Insignificant
	Likelihood Ratio	0.106202	1	0.7445	Insignificant
2. VIF (Multicollinearity) test	LNCO2(-1)	Centered VIF	6.578296	—	Acceptable
	REC	Centered VIF	9.70409	—	Acceptable
	GDP	Centered VIF	1.381403	—	No issue
	FF	Centered VIF	8.10451	—	Acceptable
	CLC	Centered VIF	2.540364	—	No issue

Test Type	Statistic	Value	df	Probability (p-value)	Decision
	TR	Centered VIF	1.607896	—	No issue
3. Heteroskedasticity Test (Breusch-Pagan-Godfrey)	F-statistic	0.341870	(24, 6)	0.9724	No heteroskedasticity
	Obs*R^2	17.90592	24	0.8075	No heteroskedasticity
	Scaled Explained SS	0.916533	24	1.0000	No heteroskedasticity

Source; Author owns calculations.

We used the Ramsey RESET test to check correct specification of the model or any inconsistency in the functional relationship between variables. The findings indicate that the t-statistics (0.285202), F-statistics (0.081340), and likelihood ratio statistic (0.106202) all have p-values above from traditional significance level of 0.05. This confirms that the findings are statistically significant. Therefore, we can reject the null hypothesis (H_0) of incorrect model specification. These results verify that the model is adequately specified and captures the link among GDP, CO_2 emissions, and energy use.

We tested the strength of multicollinearity among independent variables through Variance Inflation Factor (VIF). According to the findings, the centered VIF values for all variables (GDP, REC, FF, CLC, and TR) are below the critical level of 10, confirming the absence of severe multicollinearity. The moderate centered VIF values (ranging between 1.38 and 9.70) suggest that independent variables are not correlated with each other. Hence, the estimated coefficients are reliable, stable, and valid for inference, once again, confirming the robustness of the model.

The Breusch-Pagan-Godfrey test was used to assess heteroscedasticity issue in the model. The results show that all p-values, Prob. F (0.9724), Prob. Chi-Square for Obs*R^2 (0.8075), and Scaled Explained SS (1.0000), are above the 0.05 significance level. Hence, we cannot reject the null hypothesis of homoskedasticity, which means that the variance of the error term is constant across observations, indicating no evidence of heteroskedasticity in this model. This implies that the regression findings are statistically significant and the standard errors are reliable, and hence the empirical results are robust and valid for use in decision-making.

5. Discussion

5.1 Key findings

Key findings of the study are discussed below:

First, emissions are indirectly impacted by climate change indicators, especially temperature and weather. When the energy mix depends on fossil fuels, high temperatures enhance the need for energy for cooling, which consequently raises electricity use and emissions. Furthermore, climate variability influences industrial and agricultural production, which, in turn, influences patterns of energy use. These results demonstrate how emissions and climate change are a feedback loop in which they reinforce one another. These findings support *Anthropogenic Global Warming theory,* which assumes that human economic activities are responsible for change in planet's natural temperature because these activities have released greenhouse gases to the atmosphere through consumption of fossil fuels and increased concentrations of CO_2 in the atmosphere. These findings are corroborated by Nawaz, & Khurshid. 2022; Imtiaz, 2025; Adjei Baffour, 2025; Abebaw, (2025). who diagnosed that excessive use of fossil fuels had negative impact on CO_2 emission, which caused high temperature, resulting climate change and natural disasters.

Second, the findings predict statistically significant negative connectivity between Renewable energy use and CO_2 releases both in the short and long-term. This confirms the environmental benefits of renewable energy sources such as hydropower, wind, solar, and biomass. A green energy system results from the growing use of renewable energy technologies will reduce reliance on fossil fuels in the long-term. However, considering their current small share in overall energy supply, renewables continue to have a moderate impact on reducing emissions. Therefore, increasing the use of renewable energy is crucial for achieving the United Nations' SDG # 7, 13 & 17 which emphasize affordable and clean energy and strong actions to control climate change. These results support the findings of Awan, 2017; Dilanchiev, Umair, & Haroon, 2024; Ali, 2024; Perone, 2024; Gull et al., 2025;Duarte Alonso et al., (2025a), who confirmed negative association between renewable energy and CO_2 releases.

Third, major factor influencing CO_2 emissions is the use of fossil fuels. Ecological decline is exacerbated using coal, oil, and natural gas for transportation, industry, and electricity generation. Pakistan's energy mix is still heavily dependent on fossil fuels and has little diversification, despite efforts to introduce cleaner technologies. In addition to raising emissions, this over-reliance on non-renewable has increased the economy's susceptibility to changes in energy prices and indicate worries about energy security. These findings are also consistent with the studies of Imtiaz, 2025; Khawaja, (2025)

Fourth, the complicated relationship between international trade and carbon dioxide release also offers new insight because, on the one hand, rising industrial production and energy consumption for transportation increase emissions with trade expansion, specifically exports of energy-intensive goods. Conversely, trade openness might make it easier for clean technologies to be transferred. Overall, this study shows that trade has

increased emissions, indicating that Pakistan's trade structure has not yet changed to include cleaner or less carbon-intensive industries. Therefore, trade openness might keep pushing emissions higher in the absence of green trade policies. These findings are consistent with the *Pollution Haven Theory*, which suggests that trade openness may lead to increased CO_2 emissions in developing economies as reported by Bhayana & Nag, 2024; Bashir & Awan, 2025. In contrast, the *Pollution Halo Theory* proposes that global trade can improve environmental quality through the transfer of green technologies. The evidence of Bhayana & Nag, 2024; Khawaja, 2025; Khan & Awan, 2025 also supports the findings of our study because it confirms positive link between trade openness and CO_2 releases.

Fifth, both short- and long-term economic expansion and CO_2 releases are positively and significantly correlated. This suggests that rising energy consumption, primarily from non-renewable sources, has coincided with Pakistan's fast industrialization and growing economic activity. Growth-driven increases in manufacturing, infrastructure, and output have created a "scale effect" in which increased production levels invariably result in increased emissions. Even though economic development needs growth, the current fossil fuel-dominated energy system in Pakistan makes it environmentally unsustainable. These findings are in line with *Environmental Kuznets Curve Theory and The Energy-Led Growth Theory*. These findings support the results of Awan, 2013, Khan et al., 2024; Caglar, et al., 2024; Imtiaz, (2025), who identified positive link between Economic expansion and CO_2 releases. These findings also support UN's Sustainable Development Goals # 8, which suggests decent work and economic growth for sustainable development. Although this study is restricted to Pakistan, yet its findings can be generalized to other developing countries having similar energy system and climate issues.

5.2 New theoretical insights

The result of current research provides fresh theoretical insights into the relationship between economic expansion, energy consumption, trade openness, and ecological decline in Pakistan. These implications are discussed below in a coherent manner.

From a theoretical perspective, this study confirms and further develops several well-accepted frameworks within environmental and energy economics. The confirmation of the *Anthropogenic Global Warming theory* implies that Pakistan's increasing CO_2 releases are driven by anthropogenic economic activity, the consumption of fossil fuels. Empirically establishing the feedback mechanism between climate change and emissions adds value to existing theory by emphasizing that climate change is not only a consequence but also an active driver of emissions through increased energy demand and altered production patterns. In this respect, dynamic interaction is relevant to literature embedding climate variability in traditional emissions-growth models and suggesting bidirectional causality be explicitly considered in future theoretical models.

Further, the empirical test for the *Environmental Kuznets Curve Theory* finds that economic expansion increases emissions in the short and long run (Zeraibi, et al., (2024). Thus, the absence of a turning point indicates that Pakistan is still in the early ecologically declining stage. This adds to the EKC literature, which states that growth per se cannot assure environmental amelioration without structural changes and clean energy adoption. On this note, the energy mix plays a crucial role in determining the growth-emission relationship and further develops the EKC theory for developing economies. Moreover, the study empirically supports the *Pollution Haven Theory*, predicting that trade openness in Pakistan increases emissions by expanding pollution-intensive industries. On the other

hand, the counterview of the *Pollution Theory* suggests that trade may decrease emissions through technology transfer. By empirically finding a dominating pollution effect, the study adds to the theoretical debate that trade's environmental nexus depends on export structure and regulatory regimes. Thus, this calls for refining trade-environment theories, with institutional quality and environmental governance as intervening variables.

The negative and significant link between renewable energy use and emissions empirically supports theoretical premise of sustainable energy transition models. This suggests that a shift toward renewable energy sources decouples economic growth from environmental deterioration. However, the insignificant impact due to the small share of renewables implies that transition theories must address scale and implementation constraints in developing economies.

5.3 Practical policy implications

Based on key findings, this study provides fresh practical policy insights in Table 10 for the understanding of all policymakers and other stakeholders:

Table 10: Empirical findings and practical policy insights.

Empirical Findings	**Practical Policy Insights**
1. Climate change indicators (temperature rise and extreme weather) positively influence CO_2 emissions through increased energy demand and fossil fuel consumption, confirming a feedback loop between emissions and climate change.	1.Formulate integrated climate–energy policies focusing on reducing fossil fuel dependence. Promote energy-efficient cooling technologies and climate-resilient infrastructure to break the emissions–climate feedback cycle.
2.Renewable energy consumption has a statistically significant negative	2. Increase investment in renewable energy (solar, wind, hydropower, biomass) through

Empirical Findings	**Practical Policy Insights**
relationship with CO_2 emissions in both the short and long run.	subsidies, tax incentives, and public–private partnerships. Accelerate progress toward SDGs 7 and 13 by expanding clean energy share in the national energy mix.
3. fuel consumption is a major driver of CO_2 emissions due to heavy reliance on coal, oil, and natural gas.	3. Gradually phase out fossil fuel subsidies and implement carbon pricing mechanisms. Encourage transition toward cleaner energy alternatives and diversify the energy mix to enhance environmental sustainability and energy security.
4.Trade openness contributes to higher CO_2 emissions due to expansion of energy-intensive industries, although it also has the potential for technology transfer.	4.Introduce green trade policies, such as environmental regulations on exports and imports, carbon tariffs, and incentives for low-carbon industries. Facilitate the adoption of clean technologies through international trade agreements.
5. Economic growth is positively associated with CO_2 emissions due to increased industrialization and energy consumption (scale effect).	5.Promote sustainable economic growth by integrating environmental regulations into development planning. Encourage green industrialization, energy efficiency, and adoption of low-carbon technologies to

Empirical Findings	Practical Policy Insights
	decouple growth from emissions as suggested in SDGs # 7, 13 & 17.

Source: The Author compilation.

Data Availability statement

The data which is used in this study will be made available by corresponding author on reasonable requests.

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